Reclamation, Remediation and Hydrologic Monitoring of the Minnie Mine and Millsite, Okanogan County, Washington

Rodney T. Lentz
Okanogan and Wenatchee National Forests, Okanogan, Washington

The Minnie mine, a small cyanide heap leach gold mine near Carlton, north-central Washington was abandoned in the early 1990s. The presence of cyanide and heavy metals in the heap and process waters necessitated a series of removal and remediation actions taken by the US Forest Service under CERCLA and a parallel state law, the Model Toxic Control Act. Some contaminated fluids were batch treated using conventional methods and disposed of by land application (controlled distribution of treated solutions over a specified land area). An innovative pilot-scale In-line System process was successfully used to treat free and complexed cyanide in 45,000 liters of process pond sludges. A soil cap was constructed over arsenic-contaminated, spent ore heap materials to isolate them from people and wildlife. Suction lysimeters were installed below these solids, along with monitoring wells up- and down-gradient, to monitor potential arsenic mobilization. The capped heap, mine pit and associated disturbances were reshaped and successfully revegetated. Eight years of monitoring shows no significant down-gradient arsenic mobilization at the site.

Keywords: *mine restoration, hydrology, groundwater quality, pollution, costs, CERCLA, MTCA*

Introduction

This paper describes the successful efforts to restore the abandoned Minnie mine and millsite in north-central Washington (Figure 1) and to remediate hazardous wastes associated with the site. The paper also highlights the unanticipated efficiency and cost impacts resulting from compliance with parallel federal and state cleanup laws.

Beginning in 1983, Cordilleran, Inc., operator of the Minnie mine, initiated cyanide heap leach technology to recover gold and silver from oxidized quartz-sulfide ore mined in a small open pit located on National Forest System Lands. This operation resulted in the placement of approximately 6,300 metric tons of crushed and cement-agglomerated ore upon a 26 m by 36 m pad underlain by a 30-mil polyvinyl chloride (PVC) geomembrane liner and compacted soil. Pregnant (gold-bearing leachate) and barren (stripped and recycled fluid) process ponds constructed adjacent to this pad were about 15 m by 15 m, by 2.5 m deep, with a capacity of approximately 280,000 liters of ore heap leachate each (Figure 2). Ponds were double lined with 36-mil Hypalon liners separated by geotextile fabric and a leak detection monitoring system. A small carbon absorption/electrowinning plant was constructed to recover precious metals from the leach solutions.

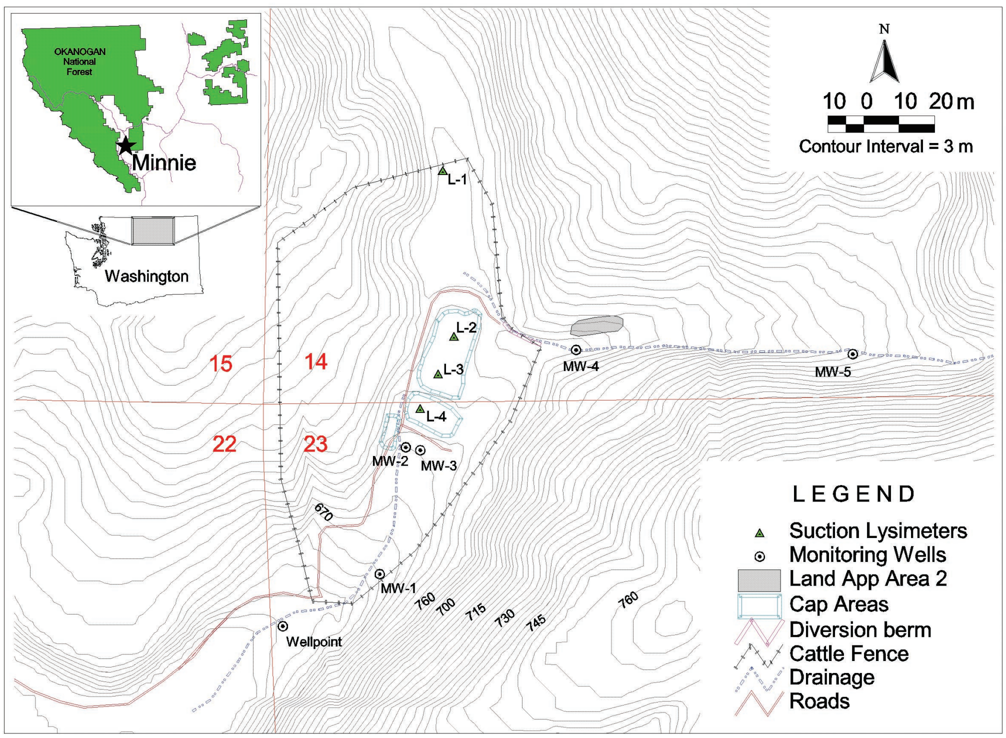
M Furniss, C Clifton, and K Ronnenberg, eds., 2007. *Advancing the Fundamental Sciences: Proceedings of the Forest Service National Earth Sciences Conference, San Diego, CA, 18-22 October 2004*, PNW-GTR-689, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

The operator discontinued heap leach operations by early 1986, but site closure implementation was delayed. Due to corporate reorganization and lack of funds, the company was searching for a buyer that was interested in restarting operations. Meanwhile, it became necessary to treat and pump process pond fluids to reduce cyanide concentrations and avoid spring-time overtopping of the ponds. Cordilleran completed some emergency work but their cash problems continued. The Forest Service's goal during this period was to work toward final site closure while maintaining safe conditions and holding the operator responsible for all costs. When it became apparent that the owner was unable to comply with their operating plan, the agency completed site work that was necessary to protect ground water, wildlife, and human health. Repayment agreements were executed by the claimant to compensate the USDA Forest Service for the cost of that effort. A buyer for the mine never materialized and eventually the claimant declared bankruptcy; the Forest Service inherited sole responsibility for cleanup in late 1990 and the operation's $7,200 reclamation bond was forfeited.

Site remediation was complicated and delayed by the interaction and perceived differences between parallel Federal and state environmental cleanup laws; the Comprehensive Environmental Response, Compensation and Liability Act, as amended (CERCLA or "Superfund", 42 USC §§ 9601) and Washington Model Toxics Control Act (MTCA, Chap. 70.105d Revised Code of Washington [RCW}). Washington Department of Ecology manages

Figure 1. Minnie mine facilities: (h) processed ore heap, (l) pad liners, (p) pregnant process pond, (b) barren process pond, (r) recovery plant. Photograph taken after the 1985 Minnie wildland fire (unrelated to the mine operations).

Figure 2. Minnie mine site location.



the MTCA program. Considerable time and energy were invested to resolve issues of authority and even report formats. While the Forest Service initially attempted to satisfy the intent of MTCA using CERCLA documents, the agency eventually produced two sets of documents for the final removal actions.

CERCLA/MTCA Process and Reports

The National Oil and Hazardous Substances Pollution Contingency Plan (NCP, 40 CFR 300) sets forth procedures for undertaking CERCLA cleanup actions and defines federal agency roles, including the Forest Service. Regarding abandoned mines, the process begins with a site assessment, which determines if a release or threat of a release of a hazardous substance has occurred. This step usually generates two reports, a Preliminary Assessment (PA) and a Site Inspection (SI), both of which document conditions at the site and the evidence of the threat or actual release of hazardous substances. If a release is evident, a Potential Responsible Party (PRP) search is conducted and documented. This step looks for parties that may be responsible for the contamination and that could participate in and pay for any cleanup actions. Cleanup response may take the form of a Removal or Remedial Action. Most Forest Service mine responses use the Removal process. Such responses demand simple to moderate levels of analysis and may be time critical in nature. Remedial action responses are typically evoked for large, complex projects that require lengthy, detailed study or those promoted to the National Priorities List (NPL) by US Environmental Protection Agency (EPA). Both processes analyze alternative response approaches and provide for public input consistent with the level of complexity. For Removals this is documented in an Engineering Evaluation/Cost Assessment (EE/CA) and for Remedial Actions, a Remedial Investigation/Feasibility Study (RI/FS).

Regulations implementing MTCA are organized under Washington Annoted Code (WAC) Chapter 173-340. These regulations outline a process which parallels CERCLA. Under MTCA an Initial Investigation and Site Hazard Assessment replace the PA/SI. All cleanup actions are documented in a Remedial Investigation/Feasibility Study (RI/FS) under MTCA.

Environmental Concerns

Initial site concerns revolved around the presence of highly toxic free cyanide and cyanide complexes in the process fluids and processed ore heap. Heavy metal contaminants, especially arsenic, cadmium and mercury, later became more prominent in the cleanup strategy.

Short Term Risks

Shortly after mine operations ceased several immediate risks became evident. Warm summer conditions favoring evaporation tended to concentrate cyanide in the process pond fluids and natural buffering reactions decreased heap and fluid pH. The combined effect was to increase the off gassing of hydrogen cyanide (HCN) to the atmosphere (Smith and Mudder 1991) thus increasing risk to nearby wildlife and humans. A substantial number of bird and bat carcasses were discovered around the ponds in July 1986.

Because precipitation on the heap continued draining to the pregnant process pond, fluid volume accumulated over time. Spring melting of winter snows on the heap sometimes threatened to overfill the ponds, spilling contaminated fluids and menacing ground water.

Long Term Concerns

Investigations at the site revealed several tasks that must ultimately be addressed:

- The treatment of contaminated process fluids and sludges accumulating in the process ponds;
- The treatment of cyanide in the processed ore heap;
- The potential for ground water contamination from pad-liner or pond leaks and from leaching of processed and unprocessed ore materials and land application soils;
- Physical reclamation of the mine and millsite facilities; and
- Long-term protection of remedial structures and reclamation efforts from storm and surface water runoff and erosion.

Restoration and Remediation

Treatment of Processed Ore Heap

The PVC liner from a second, unused pad was pulled over the exposed heap in November, 1986 to limit precipitation influx to the process ponds, which were in danger of overtopping at the time. This cover was removed one year later to facilitate heap washing and neutralization. No analyses of the processed ore heap material are available from that time, but a qualitative field test of leachate draining from the heap in August 1988 indicated >100 ppm free cyanide (CN_{Free} = unbound CN^- & HCN). By April 1989 CN_{Free} in the heap averaged about 10 mg/kg with a maximum value of 28 mg/kg. Because of contaminated drainage from the heap, it was clear that treatment of the heap solids and decommissioning of the pad was a prerequisite to the final treatment and disposal of process fluids and pond sludges.

Treatment of heap solids was accomplished over an extended time period by natural oxidation processes, influx of rain and snow melt and by circulation of neutralized process fluids and fresh water. Natural degradation of cyanide complexes was facilitated by periodically stripping the detoxified surface layer (0.7-1.0 m in depth) from the heap. The new surface was then ripped to improve overall permeability. Stripping was cost effective at the Minnie due to the relatively small size of the heap. Surface layers were removed three times between October 1989 and April 1991. The compliance standard for solids removal and final treatment was 10 mg/kg amenable cyanide (CN_{Amen}) which represents the difference between total cyanide (CN_{Total} = free + complexed CN) measured before and after alkaline chlorination treatment (USDA FS 1992). Heavy metals in the heap also had to meet RCRA (Resource Conservation and Recovery Act) solid waste criteria. Following compliance testing, the remaining heap lift and the synthetic heap liner were machine ripped to sever their hydraulic connection to the process ponds.

Treatment and Disposal of Process Fluids

Process fluids are here defined to include all solutions or supernate that report to and reside in the pregnant and barren process ponds. The operating plan called for working solutions containing 0.025 percent or 2500 ppm CN_{Total}. Dissolved constituents in these solutions varied between the two ponds and during the treatment procedures. Analysis of pregnant pond solutions in 1986 indicated 1200 ppm weak acid dissociable cyanide (CN_{WAD} = CN_{Free} + weakly bound CN complexes). Process water quality is described in Appendix A.

Fluid treatment was initiated by the operator in 1986. The intent was to detoxify the ponds and heap and dispose of excess fluid under their state waste discharge permit by land application. Alkaline chlorination (Smith and Mudder 1991) was selected by the operator to accomplish cyanide neutralization because of its relative simplicity both in technique and reagent use. This method involved the careful mixing of calcium hypochlorite ($Ca[OCl]_2$)with the pond solutions while maintaining a pH of 10.5-11.5. The hypochlorite converts CN_{WAD} to non-toxic cyanate (CNO).

Neutralization of pond fluids continued intermittently until 1993 in coordination with heap detoxification and stripping operations. Treated process fluids were land applied under Cordilleran's default National Pollutant Discharge Elimination System (NPDES) permit on two occasions and over two areas (Appendix A). The operator's discharge permit was cancelled in 1990. Washington Dept. of Ecology imposed more stringent discharge standards thereafter, which were not attainable using alkaline chlorination and sulfide precipitation (see discussion below). Consequently, the final 103,000 liters of neutralized process fluid, designated as a dangerous waste under state law (WAC 173-303) because of elevated mercury levels, was eventually trucked to a permitted treatment/discharger on Puget Sound in October 1993.

Fluid treatment at the Minnie was complicated by: (1) continued inflow of contaminated water from the heap; (2) ongoing chemical interaction with the sludges; (3) the need to prevent overtopping of the ponds; (4) high chlorine consumption; and (5) elevated mercury levels. Chlorine consumption was very high for Minnie process pond cyanide detoxification; an estimated 15-28 kg of chlorine for each kg CN_{WAD} oxidized. Early lab tests indicate 8-13 kg of chlorine would be needed for each kg of CN_{WAD} oxidized. Excessive chlorine consumption may have resulted because of inadequate reaction monitoring, reaction with sludge components, or the presence and oxidation of thiocyanide in the fluid (Smith and Mudder 1991). The operator reported copper and mercury concentrations in treated water as high as 400 and 7 ppm, respectively. The alkalinity maintained during treatment assisted in the precipitation of heavy metals present in solution as hydroxides. Sodium sulfide was mixed in the ponds as a polishing step (Smith and Mudder 1991), especially to precipitate and further reduce dissolved mercury concentrations.

Minnie ore typically contained low mercury concentrations (Appendix A). However, elevated mercury was found in the process waters and the upper part of the heap after it was washed with treated process waters. Because of the large volume of treatment reagents used it is believed that trace amounts of mercury present in the calcium hypochlorite may have accumulated during the neutralization process.

Treatment and Disposal of Process Sludges

Process sludges are defined as the low-density solids which accumulated in the pregnant and barren process ponds since their installation. Included are various incompletely dissolved chemical reagents used during operations and treatment, detrital sediment originating from the heap, chemical precipitates, dust and vegetative matter and accompanying interstitial fluids. Approximately 45,000 liters of sludge remained in the ponds after all process fluids had been removed. Chemical and Toxicity Characteristics Leach Procedure (TCLP) analyses for the sludge solids portion are displayed in Appendix A. The values indicate high levels of cyanide and heavy metals in the sludge. TCLP extracts also exceed ground water standards for cyanide and most heavy metals.

The sludge EE/CA decision (USDA FS, 1993) supported the removal and transport of process sludges as a hazardous substance to a Resource Conservation and Recovery Act (RCRA) Class C Licensed Treatment/Storage/Disposal facility (TSD). However, cyanide levels in these materials exceeded the TSD's screening values (570 mg/L $CN_{T,}$ 30 mg/L CN_{WAD}). Rather than transporting the sludge to a more distant TSD which had additional treatment capabilities and approximately doubling disposal costs, the Forest Service chose to treat the sludge using alkaline chlorination. Assisted by the USDI Bureau of Mine's scientists, the Forest Service designed and constructed a unique, pilot-scale In-Line System (ILS) to successfully treat the process solids (Figure 3). Details of the design and use of the ILS are described by Lentz and Knott (1997). Following reduction of cyanide concentrations the sludges were transported by a licensed Hazmat contractor to the TSD in September 1993 (Figure 4). Pond liners were cleaned, examined for tears or punctures, tested and removed to a land fill as solid waste.

Figure 3. ILS design for sludge treatment.

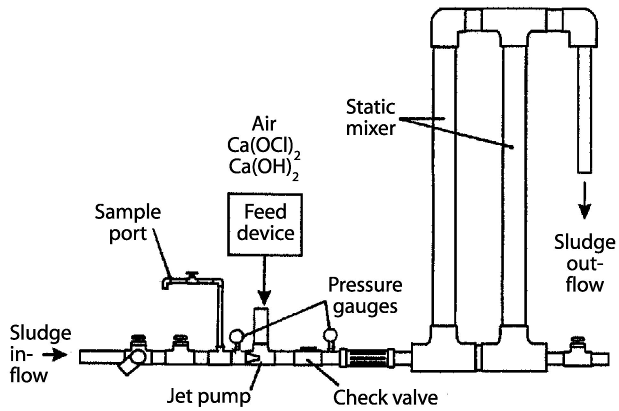


Figure 4. Following reduction of cyanide concentrations the sludges were transported by a licensed Hazmat contractor to the TSD in September 1993.

Evaluation of Ore, Heap, Process Plant, Land Application and Sub-liner Soils

A soil sampling program was developed for soils beneath or adjacent to the various mine facilities to evaluate compliance with MTCA screening levels. A total of 51 samples were analyzed: 12 beneath the heap liner; 14 beneath land application #1; 6 beneath land application #2; 15 beneath the process ponds; three from the recovery plant and three from beneath the unprocessed ore stockpile. Appendix A summarizes sampling data. Soil samples were screened against MTCA Method B soil formula values while TCLP tests were compared to MTCA Method B ground water formula values (Olympus Environmental, Inc. and USDA FS 1994a).

Process Ponds and Plant. Observations of the upper and lower synthetic pond liners and the intervening fiberglass mat (leak detection layer) showed no evidence of significant leakage through either liner. Three small, circular white stains found on the fiberglass mat may have been caused by pinhole-sized holes in the upper liner. A 2.5-cm-long tear in the lower liner (pregnant pond) about midway up the leak detection monitoring pipe (20 cm diameter PVC) was attributed to a sharp edge on the pipe. Eight centimeters of bark mulch underlying the lower liners was dry and unoxidized except for a small area around the tear which showed dark discoloration. This may have been caused by surface water moving along the leak detection pipe. Soil samples taken beneath this point and at other points beneath the ponds and at the processing plant showed no cyanide and less than screening or background levels of heavy metals. However, all but two of these samples exceeded the 1.3 ppm screening value for arsenic. For comparison, local background for soil arsenic was determined to be 26 ppm (90 percentile upper confidence limit).

Processed and Unprocessed Ore. Processed and unprocessed ore materials contained elevated metals, especially zinc, copper and arsenic, when compared to background. Nevertheless, only arsenic exceeded screening levels in these samples. The final heap samples (1993) all contained less than 0.5 ppm CN_{WAD}. TCLP leachate from processed ores exceeded ground water screening criteria for arsenic, cadmium lead, zinc and mercury (Appendix A). TCLP was run on one unprocessed ore sample. No screening levels were exceeded but the analysis did not include arsenic and lead. It is presumed that the TCLP for arsenic would have exceeded the ground water screening level.

Limited direct observations of the in situ synthetic liner found it to be in good condition where it had remained covered beneath the heap. But deterioration of the PVC was noted where it was exposed to the atmosphere, direct sunlight and mechanical impact or strain by 1990, about 7 years after installation. Some leakage was evident at the liner-outlet pipe seal. Analysis of soil underlying this connection showed substantially elevated metals compared to all other samples taken from beneath the heap liner. (880 ppm arsenic compared to 17 ppm average). All other sub-liner samples showed metal concentrations below screening levels or background. One sample exceeded the 1.3 ppm arsenic screening value.

The potential for acid rock drainage (ARD) from both processed and unprocessed ore is deemed low. Minnie mine ore is largely oxidized, containing few iron sulfide minerals. Moreover, the ore is associated with an acid-neutralizing calcium carbonate host rock (marble). Static ARD testing (modified acid base accounting) demonstrated a net neutralizing capacity of the ore, its neutralization potential/acid potential ratio or NP/AP being 9 (NP/AP ratios of 3 or greater are considered non-acid forming; USEPA 1994).

Land Application Areas. Compliance soil sampling revealed above-background levels of zinc, copper, arsenic and mercury in Land Application Area 1. Only arsenic was found to exceed the 1.3 ppm screening level. All CN_{WAD} concentrations were less than 0.5 ppm. Because Area 1 lies on mine waste rock the elevated metals may in part be attributed to background concentrations. Metals concentrations analyzed in Land Application Area 2 soils were all at or below background values. But again, arsenic exceeded the MTCA screening level.

Remedial Action and Reclamation

Final remediation and reclamation construction activities at the Minnie were completed in May 1995. The reasoning for and selection of the remedial action at the site is described in the Minnie Mine Soils EE/CA (USDA FS 1994) and the Phase I & II RI/FS (Olympus Environmental, Inc. and USDA FS 1994a, 1994b). Remedial Site work included the following activities:

- Removal of the unprocessed ore stockpile to the depressions occupied by former process ponds.
- Grading of unprocessed and processed ore storage areas and Land Application Area 1
- Distribution and mixing of ~2.2 metric tons/ha agricultural lime across the above arsenic-impacted areas to modify soil pH
- Excavation of clean native soils from an adjacent borrow area
- Distribution of native soils forming a gently sloping (<10 percent grade), 0.5-m-thick water storage cap over arsenic-impacted areas
- Installation of soil moisture sensing (gypsum blocks) and pore water sampling equipment
- Compliance sampling of cap soils
- Seeding cap of soil with native grass species
- Maintenance of the existing storm water diversion ditch/dike (as needed)

The purpose of the soil cap was two fold: (1) To isolate people and wildlife from contact with or ingestion of elevated arsenic, and to a lesser degree cadmium, found in the ore materials and land application area; and (2) to minimize infiltration of meteoric water into and through the contaminated soils. The later was based upon the capacity of the soil cap to store annual precipitation and snow melt and release it through evapotranspiration. EPA's Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al. 1986) was used to evaluate the cap design. The HELP model estimated a net annual infiltration rate of 2.5 cm/yr issuing from the base of the contaminated soils.

Soil pore water monitoring required the installation of four suction lysimeter/gypsum moisture block sets (Figure 5): one background station, one beneath the unprocessed ore, and two beneath processed ore material (Figure 2). Each set include identical primary and backup installations.

Other Reclamation Activities. Coincident with the remediation construction activities were other site reclamation efforts (Knott and Lentz 1996). The small open pit, waste rock and overburden stockpiles, the main haul road and a number of exploration cuts, pits and roads were reshaped and reseeded (Figure 6). The pit excavation was partially backfilled with waste rock and the remaining waste rock recontoured to blend with surrounding terrain. Approximately 300 linear meters of road was reclaimed by pulling back the fills into the road cut and recontouring. Approximately 3.2 hectares of total disturbance was graded and reshaped to blend with surrounding terrain and all areas reseeded with a native-species-dominated mix. Figure 7 shows the recent condition of the site.

Figure 5. Suction lysimeter installation (a), lysimeter/soil moisture block (b), and field installation (c). This typical lysimeter was used to monitor pore water beneath the processed and unprocessed ore storage areas.

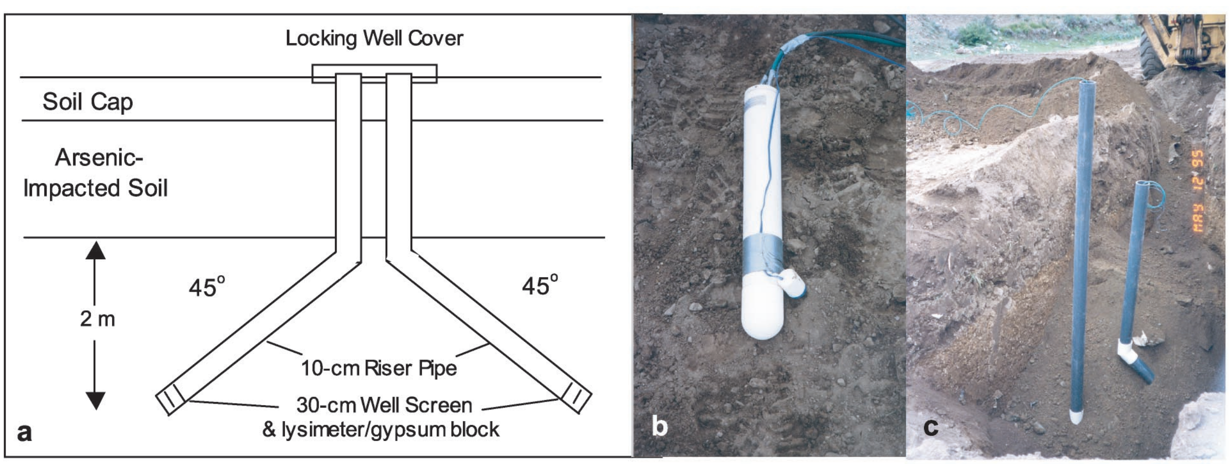
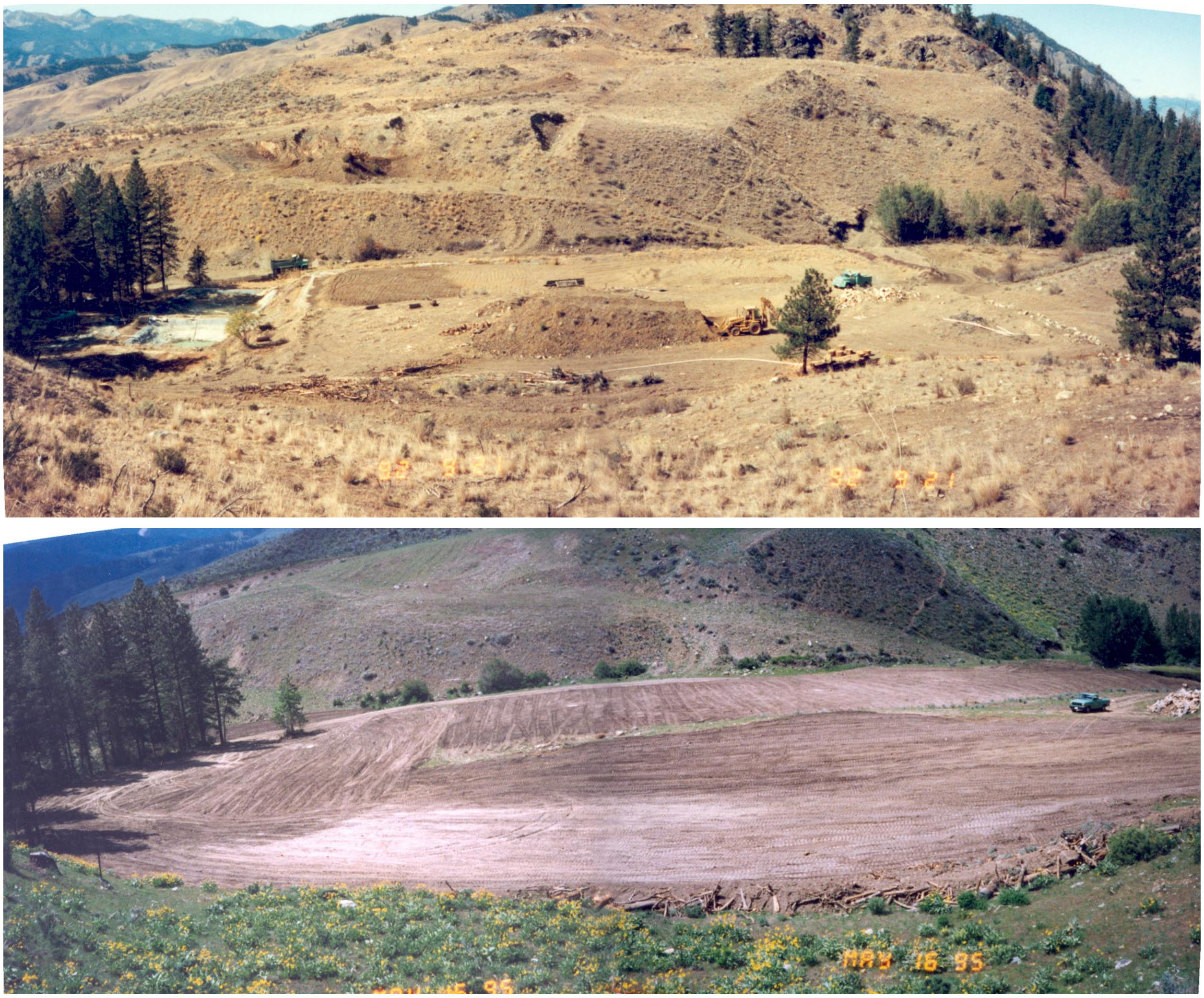


Figure 6. Comparison pre-cleanup disturbances (a) and final cap construction (b).

a

b



Site Monitoring

Monitoring requirements were designed to evaluate both cap construction and cap function. The upper 0.5 m of the cap were to meet MTCA Method A cleanup standards for arsenic (≤ 20 mg/kg) and MTCA Method B standards for cadmium (≤ 40 mg/kg). A level of 20 mg/kg arsenic was approved as the target criterion deemed to meet both metal standards. The cap and the diversion ditch and berm would be monitored for potential damage caused by erosion or deep-rooted vegetation. Background and under-cap soil pore water would be monitored, and when arsenic was present, arsenic concentrations to be determined quarterly for at least two years. Should under-cap soil pore water arsenic concentrations exceed those in the background lysimeter or, when no background sample was available, if under-cap soil pore water arsenic concentration exceeds 5 ppb arsenic, then sampling would be increased to monthly to collect statistically significant data, and the site Cleanup Action Plan (CAP) would be reopened and re-evaluated as necessary. A private drinking water well (1 mile [1.6 km] down gradient of site) was to be monitored semi-annually for 2 years.

Five up- and down-gradient ground water monitoring wells installed by the Forest Service in 1991 (Figure 2) were also monitored and sampled in conjunction with that of the suction lysimeters. A deeper, down-gradient piezometer well ("wellpoint" in Figure 2) installed by a previous operator was also monitored. Lastly, the Forest Service installed a weather station and regularly collected site weather data.

Early sampling results were evaluated in a 1995 Minnie Mine Millsite CAP Construction Report (Olympus Environmental, Inc. and USDA FS 1995). Preliminary analysis indicated background arsenic soil moisture concentrations of 11.35 mg/L, a value significantly greater than the site cleanup criterion of 5.0 µg/L arsenic. MTCA allows the use of natural background in place of the Method A cleanup standard (WAC 173-340-700(4)(d)). Therefore, the intent of the monitoring program became the collection of sufficient data to make a statistical comparison between background concentrations of arsenic and arsenic concentrations in down-gradient monitoring wells and suction lysimeters (Olympus Environmental, Inc. and USDA FS 1995).

Monitoring of the Barnett well was discontinued after approximately two years because of low arsenic concentrations in that well and in monitoring wells closer to the site.

Monitoring Results

Site monitoring results, interpretations and conclusions are discussed in detail in the Minnie CAP Monitoring Report (USDA FS 2003). Approximately eight years of monitoring (1995-2003) detected no visible evidence of structural failure or significant erosion of the soil cap. A large, summer storm event occurred in June 1998 that tested the up-stream diversion channel. This event caused deepening of the channel but did not compromise the integrity of the armored channel berm.

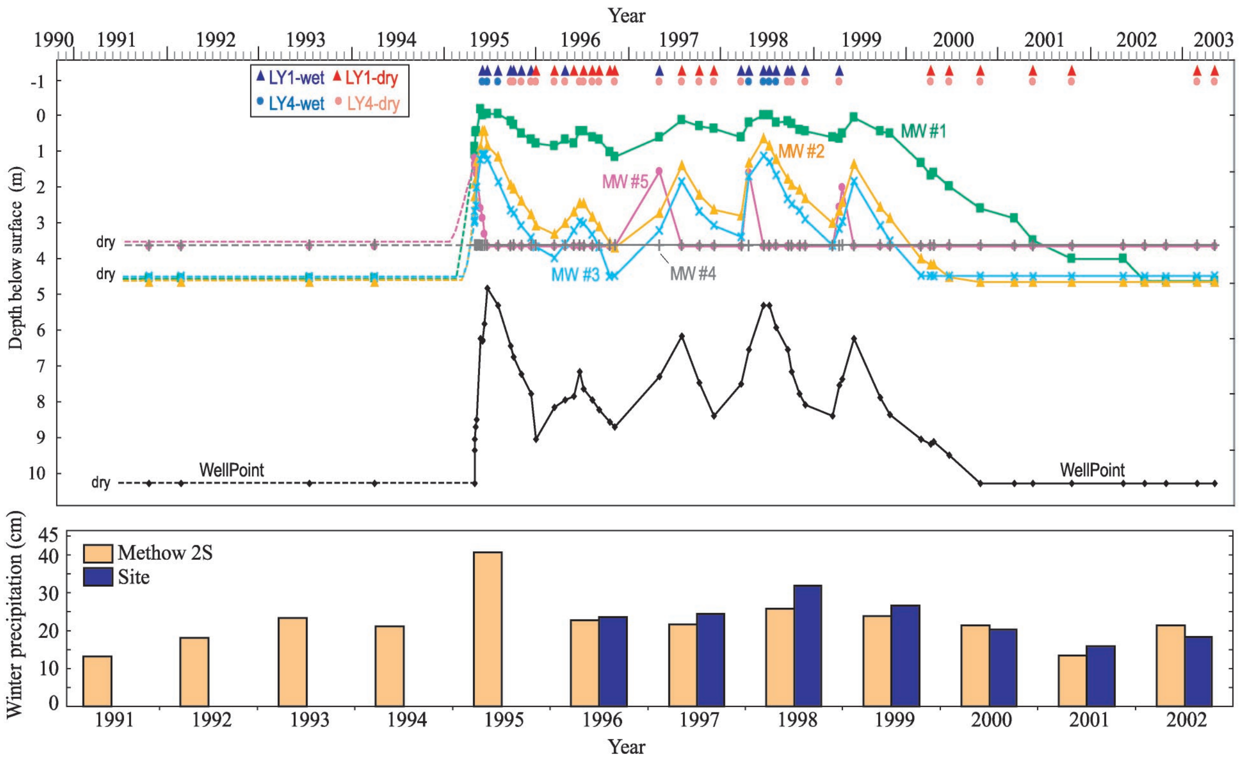
Revegetation of the soil cap and surrounding area was accomplished early and is successfully propagating (Figure 7). The CAP requirement to limit deep-rooted vegetation on the soil cap was rescinded by Washington Dept. of Ecology in 2001. Mowing of cap vegetation was therefore discontinued and sage brush has become a significant component of the cap plant community.

General Observations. Figure 8 summarizes water levels over the time period of documented observations. The condition ("wet" or "dry") of lysimeters L-1 (background) and L-4 is shown for comparison. Total winter precipitation from the nearest climatological station (Methow 2S) and the site (1995-2003) is also displayed. Monitoring data support the following general observations:

1. An anomalous occurrence of surface water and high groundwater levels at the site existed between 1995 and 2002. The change of surface and ground water manifestation was associated with unusually heavy winter (1994-95) precipitation, the first heavy precipitation year since the upper part of the drainage was denuded of timber by an August 1985 wild land fire (Figures 2 & 8).
2. Correlation of monitoring well data indicates down-drainage ground water movement on and above the bedrock/glacio-alluvial sediment interface at rates of 6-8 m/day.
3. Samples could not be drawn from the suction lysimeters when the lysimeter cups were found to be dry (i.e., when soil surrounding the lysimeter cups was unsaturated).
4. Few samples were available from L-2 and L-3, suggesting rapid transit of the spring snow melt wetting front and limited time of saturation.
5. Samples were available in L-4 only when water levels in down-gradient monitoring wells were high (within 1.3 m of the surface in MW-2).
6. Due to the return of subsurface water to normal levels it is unlikely that additional water samples will be available from L-4 or the other lysimeters.
7. The lack of observed ground water in MW-4 suggests the presence of a buried paleochannel which underlies glacio-alluvial deposits south of the existing valley .
8. The gypsum soil moisture blocks did not operate as intended. The purpose of these blocks was to help identify when adequate soil moisture was present for

Figure 7. Established site vegetation.

Figure 8. Comparison of Minnie mine ground water levels with lysimeter status and winter (Oct-Apr) precipitation.



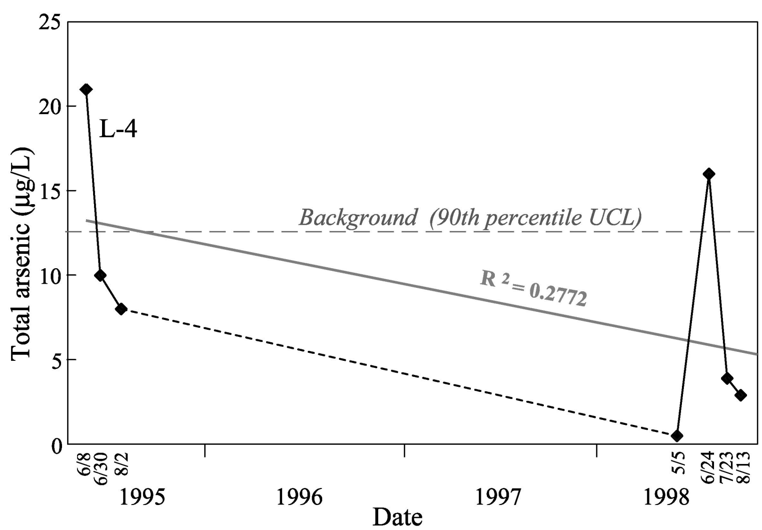
sample collection. However, in practice, soil moisture readings were consistently in the 90-97 percent range whether or not soil moisture samples could be drawn from the lysimeters. Lower moisture readings were not obtained until June 2000 and may be due to moisture block deterioration rather than actual changes in soil moisture (life expectancy is advertised at 3-5 years under irrigated soil conditions).

9. Arsenic levels in L-4 show a decreasing trend with time (Figure 9).

10. Good correlation of arsenic values in L-1 and L-4 suggests that a significant portion of the arsenic in L-4 pore water can be attributed to background arsenic levels (Figure 10).

Compliance. Compliance statistics for the Minnie monitoring stations are summarized in Table 1. Compliance requires that the 95 percentile upper confidence limit (UCL) for arsenic be less than the cleanup level, that no sample value is more than twice that standard, and than less than 10 percent of the values exceed the cleanup level. Soil sampling verified compliance with these stipulations when compared to the 20 mg/kg arsenic cap standard (Appendix A).

Figure 9. Arsenic trends in lysimeter L-4, soil pore water.



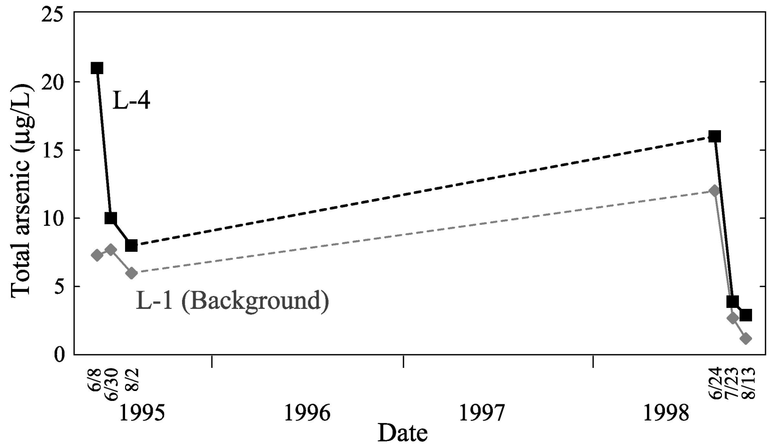


Figure 10. Correlation of arsenic values in lysimeters L-1 and L-4.

Statistical analysis of 21 background samples gives a site background value (90th percentile UCL) for arsenic in soil pore water of 12.69 µg/L. This value becomes the cleanup level for the suction lysimeters and monitoring wells.

Suction lysimeters L-2 and L-3 can not be tested statistically for compliance due to the lack of available soil pore water samples from these down-gradient points. One or no samples were collected from these stations, respectively. The single sample from L-2 showed arsenic concentrations of <1 ug/L. The apparent lack of soil moisture at these lysimeters implies compliance with soil pore water standards.

Down-gradient compliance points statistically evaluated include L-4, MW-1, MW-2, MW-3 and the Barnett well. The 95 percentile UCL for arsenic in monitoring wells MW-1, 2 and 3 were all below the 12.69 µg/L background and no samples exceeded that value.

Only seven soil pore water samples were available from lysimeter L-4. The statistical distribution of the data is lognormal and the lognormal mean, 11.07 µg/L, is below the background standard of 12.69 µg/L. However, due to the value range and small number of samples MTCAStat calculated a 95th percentile of 57.9. None of the sample values exceeded twice the background standard (25.38), but two of the seven or 29 percent exceeded background. MTCAStat estimates that some 226 samples would be necessary to obtain an upper confidence limit (UCL) of 12.5 µg/L (below background). Based upon sample availability during the past eight years this would amount to many decades of additional monitoring.

Four compliance samples from the Barnett well were available for statistical analysis. The lognormal mean for arsenic in these samples is 1.40 µg/L. No sample values exceeded background. The upper confidence limit, determined using the data set's maximum value, is 1.70 µg/L The UCL falls below the current state drinking water standard (10 µg/L) and the site's background value.

Table 1. Summary of arsenic compliance statistics for Minnie ground water monitoring samples.

Station	n[1]	Mean	Median	UCL[2]
Background	21	6.03	5	12.69
Down Gradient				
L-2	1	NA	NA	NA
L-3	0	NA	NA	NA
L-4	7	10.3	9	57.9
MW-1	22	1.73	1	2.55
MW-2	21	1.46	1	2.1
MW-3	8	2.28	2	4.33
Barnett Well	4	1.35	1.35	1.73

[1]*Number of samples*
[2]*Upper Confidence Limit; 90th percentile for background and 95th for compliance.*

Discussion. Except for suction lysimeter L-4, arsenic in all down-gradient ground water monitoring stations complies with the background standard of 12.69 µg/L. Nonetheless, the lognormal mean of arsenic concentrations in L-4 samples is below the background standard. Considering these data and the following observations the Forest Service believes that the site cleanup is protective of human health and the environment and has resulted in little or no impact to ground water quality.

Despite arsenic spikes in soil pore water from lysimeter L-4 arsenic concentrations in all down-gradient monitoring wells have lognormal means of 1.47 to 2.33 µg/L and comply with site background and the new 10 µg/L drinking water standards. Arsenic in L-4 soil pore water is decreasing, indicating diminishing availability of soluble metal in the capped material. A substantial portion of arsenic in the L-4 soil pore water can be attributed to background levels. The contribution from capped areas to ground water flow beneath the site is very small (0.04 percent) relative to the entire drainage basin. If arsenic is being mobilized down gradient of L-4 there is no indication that it has reached the nearest monitoring well, MW-2 (100 feet down gradient), after eight years of unusually high groundwater flows (Table 1).

Based upon the monitoring results regular soil pore water monitoring at the Site was discontinued. However, if site groundwater levels rose again before 2006, sampling and arsenic analysis would resume. The Forest Service would continue to inspect the site to assure the integrity of the cap and related facilities both on an annual basis and after any unusual storm events.

SITE CLEANUP COSTS

Final site cleanup costs totaled approximately $302,000. These costs are summarized by work type in Table 2. Physical remediation and reclamation work accounts for about fifty percent of the total cost. MTCA and CERCLA analyses and report preparation account for most of the remainder. A little more than half of the physical cleanup costs are attributable to the expense of the transporting process fluids and sludges classified as hazardous waste. MTCA compliance was a major cost item for the project.

Total costs by far exceeded monies collected from the reclamation surety ($7,200) and the collection agreements ($10,000). The discrepancy is, in large part, due to the unplanned costs associated with a CERCLA/MTCA cleanup and the divergence between the closure requirements originally approved in the mine operating plan and the actual cleanup implementation. However, process fluid detoxification costs were substantially underestimated and some tasks, such as dealing with potential process sludge, were overlooked completely in the initial mine permitting. These mistakes were recognized early during the cleanup process and the lessons relayed to other minerals administrators working in the field (Knott and Lentz 1990).

LITERATURE CITED

Knott, GH, and RT Lentz. 1990. Alkaline chlorination of heap leach process fluids at the Minnie Mine. In: DV Zyl, WM Schafer and ME Henderson, eds. Site Design, Construction and Reclamation of Cyanide Heap Projects. Butte, Montana: U.S. Department of Agriculture, Forest Service. Northern Region.

Knott, GH, and RT Lentz. 1996. Minnie Mine-portrait of a small heap leach cleanup [Abstract]. In: Abstracts with Programs. Geologic Society of America 1996 Annual Meeting, Cordilleran Section. Portland, Oregon: 82.

Lentz, RT, and GH Knott, 1997, Pilot-scale treatment of cyanide process sludges. In: JE Brandt, ed. Proceedings, 1997 Annual national meeting. Austin, TX: American Society for Surface Mining and Reclamation: 515-524.

Olympus Environmental Inc., U.S. Department of Agriculture Forest Service. 1994a. Minnie Mine Millsite phase I remedial investigation. U.S. Department of Agriculture Forest Service. 34 p. [plus appendices]

Olympus Environmental Inc., U.S. Department of Agriculture Forest Service. 1994b. Minnie Mine Millsite phase II remedial investigation. U.S. Department of Agriculture Forest Service. 29 p. [plus appendices]

Olympus Environmental, Inc., U.S. Department of Agriculture Forest Service. 1995. Minnie Mine Millsite cleanup action plan construction report. Okanogan, WA: U.S. Department of Agriculture, Forest Service, Minnie Mine Administrative Record. 8 p. [plus appendices]

Schroeder, PR, JM Morgan, FM Walski, et al. 1986. The Hydrologic Evaluation of Landfill Performance (HELP) model, Version 2.05.NTIS PB85-100840. 120 p.

Smith, A, and T Mudder. 1991. The chemistry and treatment of cyanidation wastes. London: Mining Journal Book Lmd. 345 p.

U.S. Department of Agriculture Forest Service. 1992. Minnie Mine preliminary assessment. Okanogan, WA: U.S. Department of Agriculture, Forest Service, Minnie Mine Administrative Record. 13 p. [plus appendices]

Table 2. Summary of Minnie mine cleanup costs.

Physical Remediation/Reclamation		$145,000
Pre-CERCLA fluid trtmt/disposal (416k liters)	$ 15,000	
Sludge trtmt/remov/trnspt/disposal (45k liters)	$ 60,500	
Fluid/liner remov/trnspt/disposal (103k liters)	$ 36,500	
Misc. reclamation	$ 9,000	
Cap const/lysimeter installations	$ 24,000	
Subtotal	$145,000	
CERCLA study/documentation		$ 17,000
MTCA study/documentation		$134,000
Post construction monitoring		$ 6,000
Total		$302,000

U.S. Department of Agriculture Forest Service. 1993. Minnie Mine engineering evaluation/cost assessment. Okanogan, WA: U.S. Department of Agriculture, Forest Service, Minnie Mine Administrative Record. 15 p. [plus appendices]

U.S. Department of Agriculture Forest Service. 1994a. Minnie Mine soils engineering evaluation/cost assessment. Okanogan, WA: U.S. Department of Agriculture, Forest Service, Minnie Mine Administrative Record. 59 p. [plus appendices]

U.S. Department of Agriculture Forest Service. 1994b. Minnie Mine Millsite cleanup action plan engineering report. Okanogan, WA: U.S. Department of Agriculture, Forest Service, Minnie Mine Administrative Record. 14 p. [plus appendices]

U.S. Department of Agriculture Forest Service. 2003. Minnie Mine Millsite cleanup action plan monitoring report. Okanogan, WA: U.S. Department of Agriculture, Forest Service, Minnie Mine Administrative Record. 8 p. [plus appendices]

U.S. Environmental Protection Agency. 1994. Acid mine drainage prediction. Technical Document EPA 530-R-94-036. 49 p.

See following three pages for Appendix A.

Appendix A. Summary of Minnie mine sample analyses. Metals tested for are shown as their chemical symbol. As = arsenic, Ba = barium, Cd = cadmium, Cr = chromium, Cu = copper, Pb = lead, Ag = silver, Zn = zinc, Hg = mercury, Se = selenium, Na = sodium, Ca = calcium, Fe = iron, Mg = magnesium, K = potassium; CN = cyanide.

	SOLIDS DATA (ppm unless otherwise indicated)																		
AREA TESTED	As	Ba	Cd	Cr	Cu	Pb	Ag	Zn	Hg	Se	CN_{Free}	CN_{WAD}	CN_{Total}	pH	Na	Ca	Fe	Mg	K
Ore Materials																			
Processed Ore																			
8/29/1989																			
no. of analyses												0							
minimum												1							
maximum												22							
average												10.2							
8/10/1992																			
no. of analyses												14							
minimum												0.4							
maximum												18							
average												3.8							
10/27/1993																			
no. of analyses	8	8	8	8	8	8	8	8	8			8							
minimum	690	100	26	34	620	120	5.7	4900	1.2			<0.5							
maximum	1800	140	91	45	810	240	14	6900	3.7			<0.5							
average	1084	124	42	40	726	178	9	5925	1.7			<0.5							
Unprocessed Ore																			
no. of analyses	4	1	4	3	4	4	2	4	1	2									
minimum	420	170	5.2	15	150	130	2.2	480	0.14	<3.0									
maximum	640	170	7.8	20	240	200	6.2	910	0.14	<3.4									
average	492.5	170	6.45	18	180	162.5	4.2	630	<0.002 - 0.14	<3.4									
Process Pond Sludge																			
6/15/1992																			
no. of analyses	4	0	4	4	4	4	4	4	4	4	1	1	1	1	4	4	4	4	4
minimum	317		389	<35	0.8	<65	58	4.4	0.05	<0.3	94	280	860	9.62	0.4	19.6	0.6	4	0.1
maximum	1510		618	95	2.7	<93	554	5.2	0.096	<0.3	94	280	860	9.62	0.8	22.7	2.6	8.7	0.5
					weight %			weight %							weight %	weight %	weight %	weight %	weight %
Subliner-facility Soil Samples																			
Site Background																			
no. of analyses	12		17	4	17	17		12						2					
minimum	3.2		0.7	11	19	3.3		224						7.8					
maximum	54		2.3	39	100	21		170						8.2					
average	12.7		1.2	25	36.4	7.8		55.6											
90 percentile (MTCA UCL)	26																		
Beneath Heap Liner																			
no. of analyses	11	12	12	12	12	10	12	11	12			3							
minimum	5.4	61	0.6	8.2	37	0.21	0.45	27	<.07			<0.5							
maximum[1]	880	140	41	28	540	140	4.6	5100	1.3			<0.5							
average[2]	17	84	3	10	53	4	0.45	76	0.1			<0.5							

[1]These values come from the soils beneath the outlet pipe leak
[2]Average excludes anomolous sample near outlet leak

Appendix A (page 2 of 3). Summary of Minnie mine sample analyses.

								SOLIDS DATA	(ppm unless otherwise indicated)										
AREA TESTED	As	Ba	Cd	Cr	Cu	Pb	Ag	Zn	Hg	Se	CN_{Free}	CN_{WAD}	CN_{Total}	pH	Na	Ca	Fe	Mg	K
Ore Materials (cont.)																			
Beneath Land App 1 (small area west of MW-2)																			
no. of analyses	12	8	14	14	14	14	1	14	14	6		6							
minimum	0.22	100	0.8	5.5	28	3.3	0.9	35	0.001	<3.7		<0.5							
maximum	160	190	6.9	54	130	58	0.9	1300	0.8	<3.7		<0.5							
average	44	139	2.4	26	63	11	0.9	280	0.18	<3.7		<0.5							
Beneath Land App 2 (small area north of MW-4																			
no. of analyses	6		4	6	6	6		6	6	6									
minimum	3		0.7	5.9	17	3		30	<0.09	<3.7									
maximum	22		1	1	3	5.5		42	<0.09	<3.7									
average	10		1	8	23	4.5		33	<0.09	<3.7									
Process Building Area																			
no. of analyses	3	3	3	3	3	3	3	3	3			3							
minimum	4.6	100	0.8	11	42	<2.2	<0.44	39	<0.08			<0.5							
maximum	7.6	150	0.9	12	54	<2	<0.44	48	<0.08			<0.5							
average	6.5	133	0.9	11	50	<2.2	<0.44	44	<0.08			<0.5							
Cap Compliance Samples																			
no. of analyses	42																		
minimum	1.3																		
maximum	26																		
average	6.05																		
95th percentile	7.56																		
								TCLP DATA	(mg/L dissolved)										
Screen Value[3]	5E-05	1.12	0.008	0.08	0.592	0.005	0.048	4.8	0.002	0.08		0.32							
Unprocessed Ore																			
11/19/1992	<0.1				<0.1			0.7	<0.002	<0.1									
Processed Ore																			
11/27/1993																			
no. of analyses	4	4	4	4	4	4	4	4	4	0		1		0					
minimum	0.079	0.71	0.12	0.005	0.24	0.034	0.005	20	0.002	0		0.07		0					
maximum	1.1	0.85	0.14	0.01	0.32	0.054	0.01	33	0.01	0		0.07		0					
average	0.8	0.8	0.14	0.008	0.28	0.040	0.009	27	0.005	<.005									
no. of exceedences	4		4		0	4	0	4	4	4		0		0					
Process Pond Sludge																			
6/15/1992																			
no. of analyses	3		3	3	3	3	3	3	1	1	1								
minimum	0.25		0.04	0.03	163	0.086	1.99	5.85	0.99	<.005									
maximum	1.21		2.4	0.1	294	0.165	13	729	0.99	<.005									
average	0.84		1.56	0.06	243	0.112	9	480	0.99	<.005	150								
no. of exceedences	3		2	1	3	3	3	3	1	0									

Metals tested for are shown as their chemical symbol. As = arsenic, Ba = barium, Cd = cadmium, Cr =chromium, Cu = copper, Pb = lead, Ag = silver, Zn = zinc, Hg = mercury, Se = selenium, Na = sodium, Ca = calcium, Fe = iron, Mg = magnesium, K = potassium; CN = cyanide.

[3] From MTCA Method B Gnd Water Criteria

Appendix A (page 3 of 3). Summary of Minnie mine sample analyses. Metals tested for are shown as their chemical symbol. As = arsenic, Ba = barium, Cd = cadmium, Cr =chromium, Cu = copper, Pb = lead, Ag = silver, Zn = zinc, Hg = mercury, Se = selenium, Na = sodium, Ca = calcium, Fe = iron, Mg = magnesium, K = potassium; CN = cyanide.

	PROCESS FLUIDS ANALYSES (mg/L total constituent)																		
AREA TESTED	As	Ba	Cd	Cr	Cu	Pb	Ag	Zn	Hg	Se	CN_{Free}	CN_{WAD}	CN_{Total}	pH	Na	Ca	Fe	Mg	K
Barren Pond																			
11/14/1986	<3	<0.1	<0.04	<0.4	490	<1	5.6	250	8.6	-	10	-	340		4700	1300			
10/8/1987 (1st Land App.)	0.08	0.05	0.007	<0.01	1.9	<0.02	0.23	0.99	0.091	5.36		<0.05		11.2	5500				
Pregnant Pond																			
11/14/1986	<3	<0.1	2.9	<0.4	510	<1	10	350	1.7	-	10		1200		2100				
9/21/1989 (2nd Land App.)	0.08	0.05	0.01	<0.02	4.8	<0.01	0.2	-	0.0034	<0.1		0.05		8.6	500				